On the Impact of the Dominant Intelligences of Players on Learning Outcome and Game Experience in Educational Games: The TrueBiters Case

Pejman Sajjadi(✉), Eman El Sayed, and Olga De Troyer

Department of Computer Science, WISE,
Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium
{Ssajjadi,Eman.el.sayed,Olga.DeTroyer}@vub.ac.be

Abstract. This paper presents a digital educational game, TrueBiters, developed in order to help students practice the use of the truth tables to compute the truth-value of logical expressions in proposition logic. Next to improving the pass rate of our logic course, we also use the game to investigate whether there is a difference in learning outcome and game experience for students with different dominant types of intelligences. The results of a pilot study show that the use of TrueBiters resulted in an improvement of the learning outcome for logically-mathematically intelligent players. The results of a pilot study on game experience show differences for kinesthetically intelligent and logically-mathematically intelligent players with respect to certain game experience aspects. The number of participants was too small to draw definitive conclusions, but the results are an indication that the dominant types of intelligences do matter for the effectiveness of an educational game.

1 Introduction

The logic course in the 1st Bachelor Computer Science at our university is since years a stumbling stone for the students. On average less than 30 % succeed in the exam on the first try. Dealing with the formal and abstract language of logic is hard for most students. They easily lose interest and exhibit procrastination, and after a while they are completely lost. We tried to remedy this behavior in different ways but didn't succeed. Since educational games are commended as an enjoyable and effective way for learning and given our own research interest in games for learning, we decided to develop an educational game for the course.

We decided to first focus on practicing the truth tables of proposition logic, as a good knowledge of the truth tables is essential for understanding more complex topics introduced in the course. The TrueBiters game is a two-player game, inspired by a card game called "bOOleO" on Boolean logic[1]. We adapted the game to proposition logic and digitized it. Since most of our students have a smartphone and playing games on

[1] https://boardgamegeek.com/boardgame/40943/booleo.

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smartphones is popular among youngsters, we decided to develop a game for which they could use their smartphone with typical gesture-based interactions.

In addition, we wanted to use the TrueBiters game as a case study for our research on player-centered serious game design. We are investigating whether taking individual differences among players into consideration during game design can be beneficial for the game and/or learning experience [1, 2]. One direction that we explore is the use of the theory of Multiple Intelligence (MI). According to the theory of MI [3] the intelligence of a human being is multi-dimensional, in contrast to the commonly known one-dimensional Intelligence Quotient (IQ). In MI, eight distinct intelligence dimensions are proposed, each representing a different way of thinking, problem solving and learning. These dimensions are: visual-spatial, bodily-kinesthetic, logical-mathematical, linguistic, interpersonal, intrapersonal, musical, and naturalist. Everyone possesses every intelligence but to different degrees and all dimensions work together in an orchestrated way. We recognize that there are controversies about this theory. Opponents (e.g. [4–6]) criticize the lack of strong empirical evidence for the existence of the dimensions, while proponents [7] that the value of such a theory is rather in the contributions it could make to understanding and practice in the field. Therefore, we deem researching whether this theory can be used in understanding players' behavior and attitude worthwhile.

We used the TrueBiters game as a case study to investigate whether there would be a difference in learning outcome and game experience for students with different dominant types of intelligences. The results of a pilot study show that the use of TrueBiters resulted in an improvement of the learning outcome for logically-mathematically intelligent players. The results on game experience show that bodily-kinesthetically intelligent and logically-mathematically intelligent players demonstrate different experiences with respect to certain game experience aspects. The number of participants in the pilot study was too small to draw definitive conclusions but the results are a strong indication that the dominant types of intelligence do matter for the effectiveness of an educational game. Therefore, in the context of player-centered serious game design it may be important to take the intelligences of the target players into consideration when designing a learning game.

The paper is organized as follow: in Sect. 2 we review other educational games related to teaching logic or applying MI. Section 3 explains the TrueBiters game. Section 4 discusses the evaluation of TrueBiters both from a learning point of view and a game experience point of view, and Sect. 5 concludes the article.

2 Related Work

One of the first educational games related to logic is Robky's Boots (RB) [8]. In this game the players are introduced to the basic operations of logic, which they can use to construct arguments modeled as "machines", which is a composition of different logical gates and different electrical components. The objective of the game is to build a machine that can be turned on and off. In 1982 when this game was first introduced, it was perceived as intrinsically enjoyable and interesting by its players.

In [9] a serious game for learning and practicing propositional logic was introduced and evaluated. The game can be played with multiple users, collaboratively, cooperatively or competitively. The game is composed of eight modes (similar to levels) where each mode represents a different type of instruction and practice. The logical concepts are taught in a very abstract way using formulas, exactly as in textbooks on logic. Moreover, the practicing takes place through multiple-choice questions at the same abstract level. The results of the evaluations of this game indicate that it was perceived as easy to use, helpful, fun and motivating.

In [10] a prototype of a narrative-based interactive learning environment aimed at providing a rich and engaging learning experience for teaching binary arithmetic and logic gates was introduced and evaluated. The environment uses a fantasy narrative to contextualize the learning and domain knowledge. There is a computer on a ship that acts as the tutor to the player and then tests the player's understanding through a series of tasks. The results of the evaluation on learning using pre and post-tests and a control group showed that the game improved the test scores of the players in the post-test. Furthermore, the game was perceived as enjoyable by the players.

With respect to non-digital games, "bOOleO" is a strategy card game that employs the principles of Boolean algebra. It is a two player competitive game, and the goal is to reduce a list of bits by building a pyramid using Boolean operators and logical gates. Similarly, in [11] a (non-digital) board game, "The Logic Game", was proposed with the objective of providing students an effective way to understand and remember logical operators. An experiment with students taking a logic course showed that playing this game had a significant impact on their skills and understanding of logic.

On similar grounds, but from a more theoretical and pedagogical point of view, the research in [12] investigated the role of games as a tool in developing the logical-mathematical intelligence of MI. It was concluded that educational games in general will help players develop their logical reasoning abilities, since educational games push players to constantly analyze and solve problems.

To the best of our knowledge there are hardly any researches investigating the relationship between MI and learning outcome or game experiences in the context of serious games.

3 TrueBiters

TrueBiters is a digital two-player game for practicing the basic logical operators of propositional logic. It is played over two smartphones and a tablet. The game is inspired by the card game "bOOleO". While bOOleO is using Boolean logic, we applied its principles to proposition logic and digitized the game, which allows for an automatic verification of the rules of proposition logic. The game has a common area composed of tiles (i.e. the board - Fig. 1. (b)), which is rendered on a tablet. The different propositional operators are applied and displayed on the tiles. Furthermore, the game uses two smart phones, each operated by a player and containing a stack of cards representing logical operators that can be used by a player to perform an action on the common area. The three physical components are connected and synched using Bluetooth technology; the tablet is the master and the two smartphones are the slaves.

The game is using five logical operators represented by symbols representing fictive animals that can eat bits (Table 1). As is common in logic, the bit 1 represents TRUE and the bit 0 represents FALSE. Each binary logical operator (AND, OR, IMPLY, and EQUIVALENT) comes in two versions: one that results in a 1-bit and one that results in a 0-bit. For instance, the OR operator takes two bits as input and can either result in 0 or in 1 (depending on the input values). Next to these symbols, there are two error symbols, the invalid-symbol to indicate that an action cannot be applied to a tile because one or both inputs are not yet defined, and the wrong-symbol to indicate an incorrect action, e.g. the 1-version of the AND operator used on two 0-bits (which is incorrect according to the truth table of the AND operator).

Table 1. TrueBiters symbols

Logical operator symbols			
	**OR**		**IMPLY**
	**AND**		**EQUIVALENT**
	**NOT**		
Error symbols			
	**WRONG**		**INVALID**

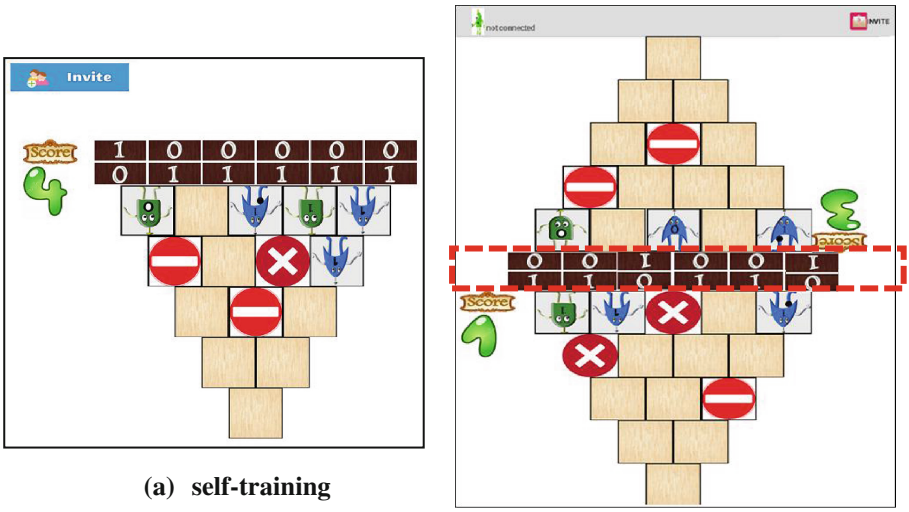
Once the game commences each player receives a list of six bits. The values of these six bits are randomly generated. One player receives this list and the other player receives the inverted version of the list (Fig. 1(b)). Each player has to reduce his list of bits to a single bit being the right most bit of his list. The first player that achieves this is the winner. To do so, the player should use the correct logical operator cards that he has available on his mobile phone. For instance, he can reduce a 0-bit and a 1-bit into a 0-bit by using the 0-version of the AND operator. The players play alternately. If a player doesn't have a suitable operator at his disposal he has to skip his turn. The reduction process is guided by filling a pyramid of tiles. Each player has his own pyramid (Fig. 1(b)). The players select the tile they want to fill on the tablet by tapping on that tile, and swiping the desired card from their smartphone to that tile. If the action was allowed and correct the corresponding symbol will show up on the tile, otherwise the appropriate error symbol is displayed. By making a correct move, the player will earn a point; by making a mistake, he will lose one. Each player, at their turn, can only make one move. The version of the operator used determines the value of the tile, i.e. a 1-card version results in a 1-bit tile and a 0-card version results in a 0-bit tile. In this

way, the tiles can be used as input for future operators. For example, in Fig. 1(b) the player using the top side of the board has chosen the AND operator with output value 0, to reduce the two rightmost bits (0 and 0) into a 0-bit.

Moreover, each player has the possibility to switch one of the initial bits with the corresponding bit of the other player. To do this, the player should have a NOT operator card available on his smartphone. He then selects the bit to be switched by tapping on it and swipes the NOT card to the board. This action will invalidate the results of that branch for both players, potentially resulting in extra work for the opponent. The opponent can directly cancel this action by also using a NOT card.

Each player starts with four randomly chosen operators in their card stack and can browse through them by swiping left or right. Selecting a card (i.e. use the card for the selected tile) is done by swiping up. When a card is used, it is removed from the card stack and replaced by a new card. A player can skip his turn by discarding a card. This is done by not selecting a tile on the board and swiping the desired card up, upon which a new card will be added to his stack.

The game also allows for self-training in order to become familiar with the game and to learn the different operators. The only difference is that in the self-training mode only one pyramid is shown (see Fig. 1(a)) and only one smartphone is needed.



(a) self-training **(b) game session**

Fig. 1. TrueBiters' board

4 Evaluation

4.1 Learning Outcome Evaluation

Before rolling out the game in our logic course, we first performed a pilot study to investigate the potential learning outcome of the game as well as the game experience. We invited those students from our logic course that failed their exam in the first

session to participate. Because those students clearly didn't manage to master the course, they would be a good audience to test the effect of the game on. Although the students were incentivized through a gift and were assured complete anonymity, only four students (male) (out of 38) volunteered to participate.

In order to see to what degree the participants would improve after playing TrueBiters, we used a "pre-test[2]" and a "post-test[3]". The two tests were different in questions but we made sure to maintain the same level of difficulty. In the tests, the students had to resolve some questions requiring the use of the truth tables for the standard logic operators. During the course, they did similar exercises.

In order to see whether the differences in their learning outcome, if any, could be attributed to differences in intelligence dimensions, we measured their intelligence levels using the Multiple Intelligences Profiling Questionnaire (MIPQ) [13].

Before the players start the game, they were asked to do the pre-test and fill out the MIPQ. Afterwards, the game was explained and they were given 10 min for self-training. Next, they played the game (in the form of a tournament). After the play sessions, the participants were asked to do the post-test and fill-out a game experience questionnaire, 33 statements to be rated on a scale of 0 to 4 (0: not at all and 4: extremely) (see [14, 15] for more information). This questionnaire measured the participants' experiences in terms of their competence, immersion, flow, tension, challenge, negative affect and positive affect.

Since TrueBiters is a two-player game, in order to avoid any potential negative influence caused by a weak player, we organized the gameplay sessions in form of a tournament in which each of the four players played against each other. Therefore, in total each participant played three times and we had a total of six games. The comparison between the pre and post-test results are depicted in Fig. 2.

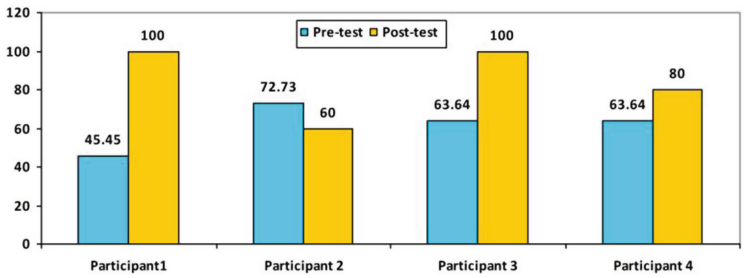


Fig. 2. Results of the pre and post-test (maximum score is 100)

The results of the post-test were significantly better for all participants except for participant two. To try to understand why participant two didn't improve (in fact he did worse), we investigated the results of the MI questionnaire. The results of this

[2] https://www.scribd.com/doc/316851385/Pre.

[3] https://www.scribd.com/doc/316851442/Post.

questionnaire indicated that all participants expect participant two exhibit the **logical-mathematical** intelligence as one of their dominant intelligences. Participant two on the other hand, exhibits the **linguistics** intelligence as his dominant one. The logical-mathematical intelligence is defined as the capacity to conceptualize logical relations among actions or symbols, while the linguistic intelligence is defined as sensitivity to the meaning, order, sound, rhythms, inflections, and meter of words [16]. This difference may explain why participant two didn't make the same improvement as the three other participants in the same amount of time. Whether he would be able to improve after more practicing or he would never be able to master the topic within a reasonable time cannot be derived from this pilot study. We will investigate this with a more large-scale study lasting over a complete academic year.

4.2 Game Experience Evaluation

Since the results of our pilot study showed that dominant MI dimensions might be an influencing factor in the learning outcome, we wonder whether it would also influence the game experience of the participants. Therefore, in addition to the game experience results of our four participants in the pilot study, seven more participants (six male and one female) played the game. These participants were students from the second year Bachelor in Computer Science who already passed the exam of the logic course. The intelligences of these participants and their game experience were measured in the same way as in the previous evaluation. They were also given 10 min for self-training before playing the game. We didn't do the pre and post-test as we expected that they would already have a good knowledge of the logic operators and therefore most likely would show no improvement. These participants played the game twice. For these participants, the focus was purely on the game experience.

The results of the MIPQ of all 11 participants (4 from the first study and the 7 additional participants) showed that 82 % (9 players) of our population had the logical-mathematical intelligence as one of their dominant intelligences (which is not surprising as these are all students in Computer Science). A comparison between the game experience results of the logically-mathematically dominant participants and the others is shown in Table 2. We see that the logically-mathematically dominant participants were experiencing more challenge, more competence, immersion and flow. This suggests that TrueBiters is providing a proper balance between challenge and competence for the logical-mathematical dominant participants, as they are more immersed in the game and experiencing the flow state [17] more than the rest of the participants. A good game experience can potentially result in an increase of attention and motivation that may ultimately result in increased learning outcomes [18, 19]. However, they were slightly feeling more tension, slightly less positive affect, and more negative affect. This could be due to the fact that the interaction modality of TrueBiters is inherently kinesthetic, i.e. gesture-based. Therefore, we decided to see what percentage of our population was highly kinesthetic and how these highly kinesthetic participants experienced the game compared to the rest. The results of the MIPQ showed that 36 % (4 players) of our population had the kinesthetic intelligence as one of their dominant intelligences. As shown in Table 2 these participants were

experiencing less tension and less negative affect. This can be explained by the fact that the gesture-based interaction better suits this group and can explain why the participants who do not have kinesthetic intelligence as one of their dominant ones score lower on these aspects. Therefore, we analyze TrueBiters based on its mechanics and their relation to these two intelligence dimensions using the recommendation tool introduced in [1]. This tool provides an evidence-based mapping between the MI dimensions and game mechanics; it indicates for each MI dimension which mechanics are appropriate (i.e. have a positive correlation with the dimension), are inappropriate (i.e. have a negative correlation), and for which no clear recommendation can be given (marked as "dubious"). The results are given in Table 3.

Table 2. Game experience results

	Logical	*Rest*	*T-test*	*Kinesthetic*	*Rest*	*T-test*
	Mean	*Mean*	*Sig. 2-tailed*	*Mean*	*Mean*	*Sig. 2-tailed*
Competence	2.37	1.9	0.54	2.05	2.42	0.54
Immersion	2.15	1.1	0.02	1.65	2.14	0.23
Flow	1.88	1.6	0.57	1.95	1.77	0.68
Tension	0.4	0.33	0.89	0.16	0.52	0.4
Challenge	1.35	1.2	0.7	1.2	1.4	0.54
Negative affect	0.58	0.25	0.4	0.5	0.53	0.91
Positive affect	2.71	2.8	0.83	2.55	2.82	0.4

Table 3. Analysis of TrueBiters in terms of mechanics and their relation to MI dimensions

Mechanic	Kinesthetic Intelligence	Logical-mathematical Intelligence
Motion	✓ positive	-
Repeat Pattern	✓ positive	✓ dubious
Memorizing	✓ negative	-
Submitting	✓ positive	-
Points	✓ positive	✓ positive
Quick feedback	✓ dubious	✓ positive
Modifier	✓ dubious	✓ positive
Disincentives	✓ negative	✓ negative
Companion gaming	✓ positive	✓ positive
Tutorial/first run scenarios	✓ dubious	✓ positive
Logical thinking	-	✓ positive
Strategizing	-	✓ positive
Browsing	-	✓ negative
Choosing	-	✓ negative

From this analysis we can conclude that TrueBiters employs a lot of game mechanics that are appropriate for the logical-mathematical dimension, i.e. *logical thinking*, *strategizing*, *modifier*, *points*, *quick feedback*, and *tutorials*. *Repeat pattern* is "dubious" for this MI dimension meaning that positive as well as negative correlations were found earlier. Some of these mechanics are also correlated (positive or dubious) with the kinesthetic dimension: repeat pattern, points, quick feedback, modifier, and tutorial. However, the mechanics browsing and choosing are negatively correlated to the logical-mathematical dimension and the mechanic disincentives (i.e. lose points) is negatively correlated with both MI dimensions. This analysis might explain why the logical-mathematical participants were feeling tension and negative affect while experiencing the flow state at the same time. It could also explain why the kinesthetic participants were experiencing less competence, immersion and challenge: the key gameplay mechanics (*strategizing* and *logical thinking*) are logical-mathematical oriented, and there is a negative correlation for the bodily-kinesthetic intelligence with the *memorizing* mechanic (i.e. remembering the truth tables, which is vital for being successful). These results are an indication that the dominant intelligences of players do play a role in the effectiveness of a learning game. It is also an indication that the popularity of game mechanics and interaction modes (e.g. gesture-base interaction) is not necessarily a guarantee for success.

It is important to mention that, due to the small number of participants used, analyzing if the differences for the different game experience aspects among the different groups of players were significant or not in unlikely to lead to interesting results. Nevertheless, based on a T-test analysis for each aspect of game experience between all groups, we observe that the experienced "immersion" by the logically-mathematically intelligent players was significantly higher than for the rest ($P < 0.05$).

5 Conclusions and Future Work

We presented an educational game developed in order to help students practicing the use of the truth tables to compute the truth-value of logical expressions in proposition logic. Although the number of participants used for the evaluation of the learning outcome in our pilot study was small, the results of our pilot study were promising: 3 out of 4 participants performed better in a logic test after playing the game compared to their result of a similar test taken before playing the game. The common denominator of the participants who showed improvement, with respect to the theory of MI, seems to be their dominant logical-mathematical intelligence. Furthermore, it was also observed that the dominant intelligence is also a contributing factor for the game experience. It was shown that for TrueBiters, which employs mostly mechanics positively correlated to the logical-mathematical dimension, the game experience of players with a high logical-mathematical intelligence was higher than for the other players (at least significantly with respect to immersion). We also observed a negative influence on some game experience aspects from the use of some negatively correlated game mechanics for these players. This is an indication that it is important to take the dominant intelligence of the target audience into consideration when designing a learning game.

In future work we will try to replace the negatively correlated game mechanics for the logical-mathematical dimension by better ones (or allow for a choice) and investigate whether this gives different results for the affected game experience aspects. Furthermore, a more large-scale experiment involving a control group, running over a longer period will be performed in the coming academic year. This is needed, since due to the low number of participants, we are not able to make generalizable conclusions at this point. Moreover, the quantitative research approach used need to be complemented with qualitative measures (i.e. interviews, observations) in order to gain a deeper understanding of the game experiences of the players, and their gained level of knowledge.

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